Integrated GPS/eLoran Systems

by

G. Linn Roth, Ph.D., FRIN
Locus, Inc.

5th ICNS
May 3, 2005
Fairfax, VA

Outline

- Loran interest and enhanced or eLoran
- FAA GPS/Loran integration programs
  - Rockwell Collins and Locus
  - FreeFlight Systems and Locus
- Results
- Summary

Resurgence in Loran Interest

- **DOT's Volpe study on GPS vulnerabilities spurred interest in independent, backup systems for both navigation and timing, i.e. critical infrastructure areas**

"VULNERABILITY ASSESSMENT OF THE TRANSPORTATION INFRASTRUCTURE RELYING ON THE GLOBAL POSITIONING SYSTEM"

- **New GPS policy specifically identified need for backups**

"US Space-Based Positioning, Navigation, and Timing Policy," December 15, 2004

Resurgence in Loran Interest

- **Extensive DOT Loran technical evaluation positive:**

"Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation and Time Applications"

- Both the technical evaluation and the benefit/cost study ***strongly support*** retaining a modernized Loran-C system as a part of the mix of radionavigation systems provided by the US government.

See http://www.locusinc.com/pdf/press/

Resurgence in Loran Interest

- Program described is part of FAA program evaluating eLoran's ability to meet Required Navigation Performance (RNP) 0.3 criteria for accuracy, availability, integrity and continuity requirements for Non-Precision Approaches (NPAs)

- FAA has identified Loran as "best theoretical" GPS backup

- Note: FAA plans migration toward "free flight" environment and Loran is a RNAV system

What is enhanced or eLoran?

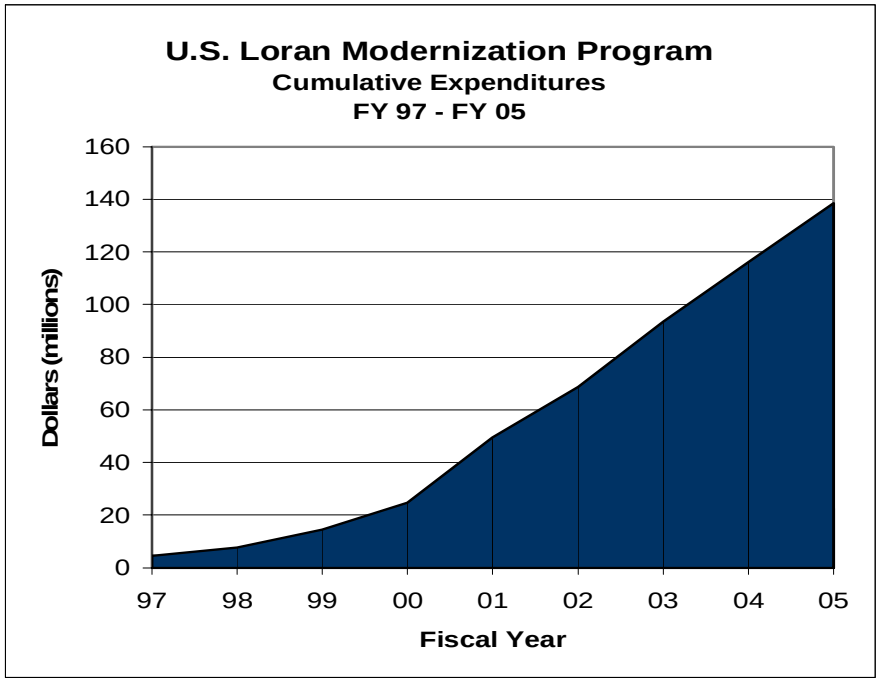
- **eLoran transmitter system:**
  - solid state transmitters with state-of-the-art time and frequency clock measurement and control equipment (TFE)
  - 3 Agilent 5071A Cs at each transmitter, likely forming largest distributed primary clock system in the world
  - TFE uses GPS data to steer ensemble averaged 5071A's and to provide ~15 ns UTC (USNO) recovery at each transmitter
  - transmitters will use time-of-transmission control ala GPS
  - new 9th pulse will be added that is pulse position modulated (PPM):
    - Provides UTC, leap seconds, station identification, differential Loran corrections, etc.
    - Means users only require strongest signal to get absolute time
  - Modernizing other equipment and operational procedures will significantly improve accuracy, availability, continuity and integrity

What is enhanced or eLoran?

- **eLoran receiver:**
  - All-in-view (40+ station tracking)
  - Digital noise blanking (lightning)
  - Adaptive interference cancellation
  - Integration with GPS
  - Real time ASF calculations
  - Rapid signal acquisition, reacquisition, etc.

- **eLoran antenna:**
  - H-field antenna (p-static immunity)
  - Incorporates SAG
  - Small (10 x 20 cm)
  - Combined GPS/H-field antennas

Modernization of US Infrastructure Toward eLoran is Well Underway



- US Congress has provided strong bipartisan support for Loran since 1997, and $22.5M in additional modernization funding was approved for FY2005.
- Loran infrastructure upgrade well underway, and system performance will continually improve as modernization progresses.

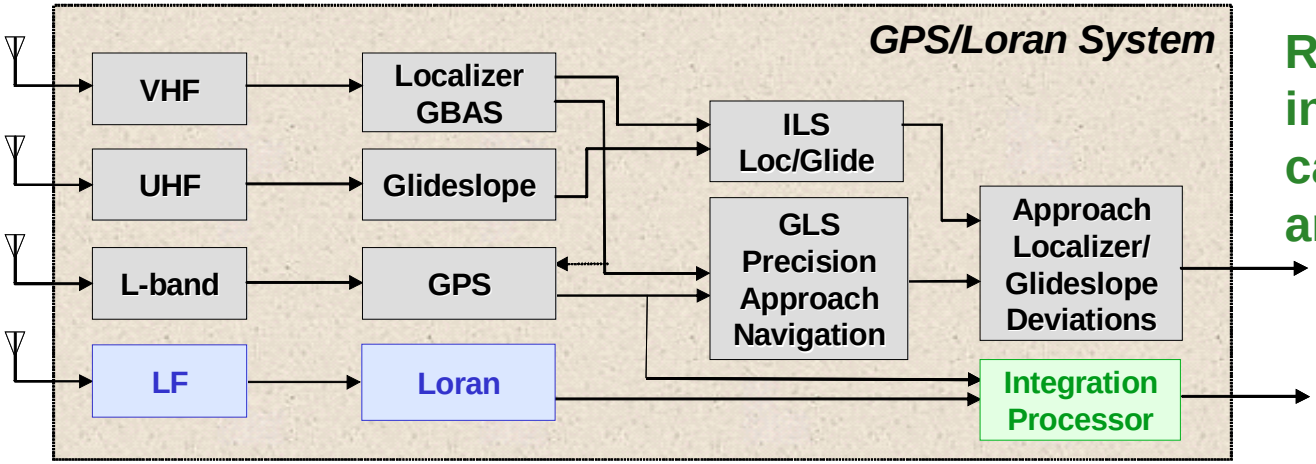
Performance Requirements for eLoran

	Accuracy	Availability	Integrity	Continuity
Current Definition of Capability* (US FRP)	0.25 nm (463 m)	0.997	10 second alarm/ 25 m error	0.997
FAA NPA (RNP 0.3)** Requirements	0.16 nm (307 m)	0.999 - 0.9999	0.9999999 (1×10^{-7})	0.999 - 0.9999 over 150 sec
US Coast Guard HEA Requirements	0.004 - 0.01 nm (8-20 m)	0.997 - 0.999	10 second alarm/ 25 m error (3×10^{-5})	0.9985 - 0.9997 over 3 hours

* Includes Stratum 1 frequency capability
** Non-Precision Approach Required Navigation Performance

(from Narins, ENC GNSS 2004)

Rockwell/Locus GPS/Loran Integration Program



Rockwell Collins integration processor card combines GPS and Loran data

Locus Loran receiver card is installed on the MMR door in place of the MLS

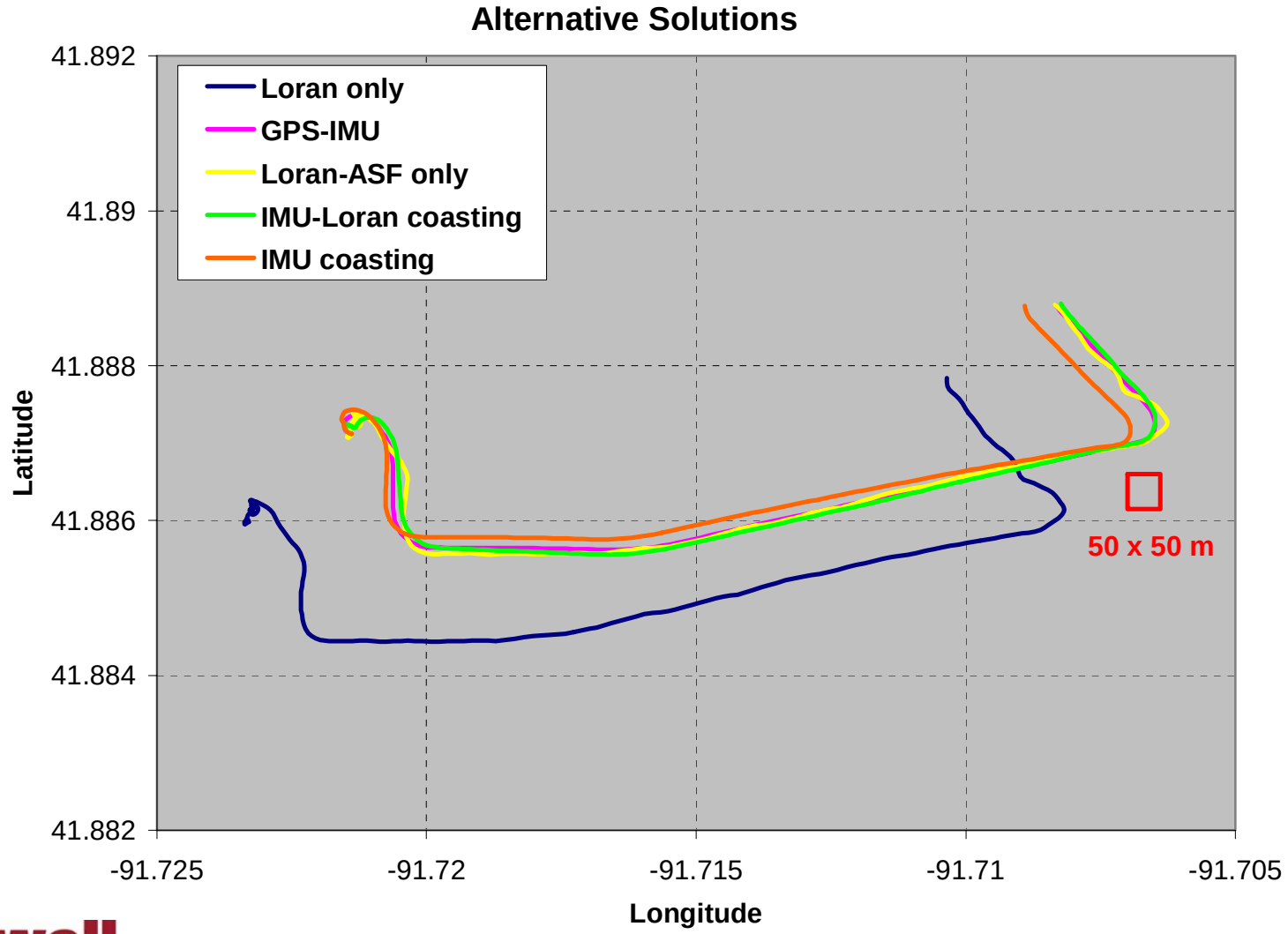
Rockwell multimode receiver (MMR) is prototype platform (see GPS World, May, 2003)

Rockwell Integration of GPS-IMU-Loran

- **AHC-3000A AHRS modified to add IMU outputs**

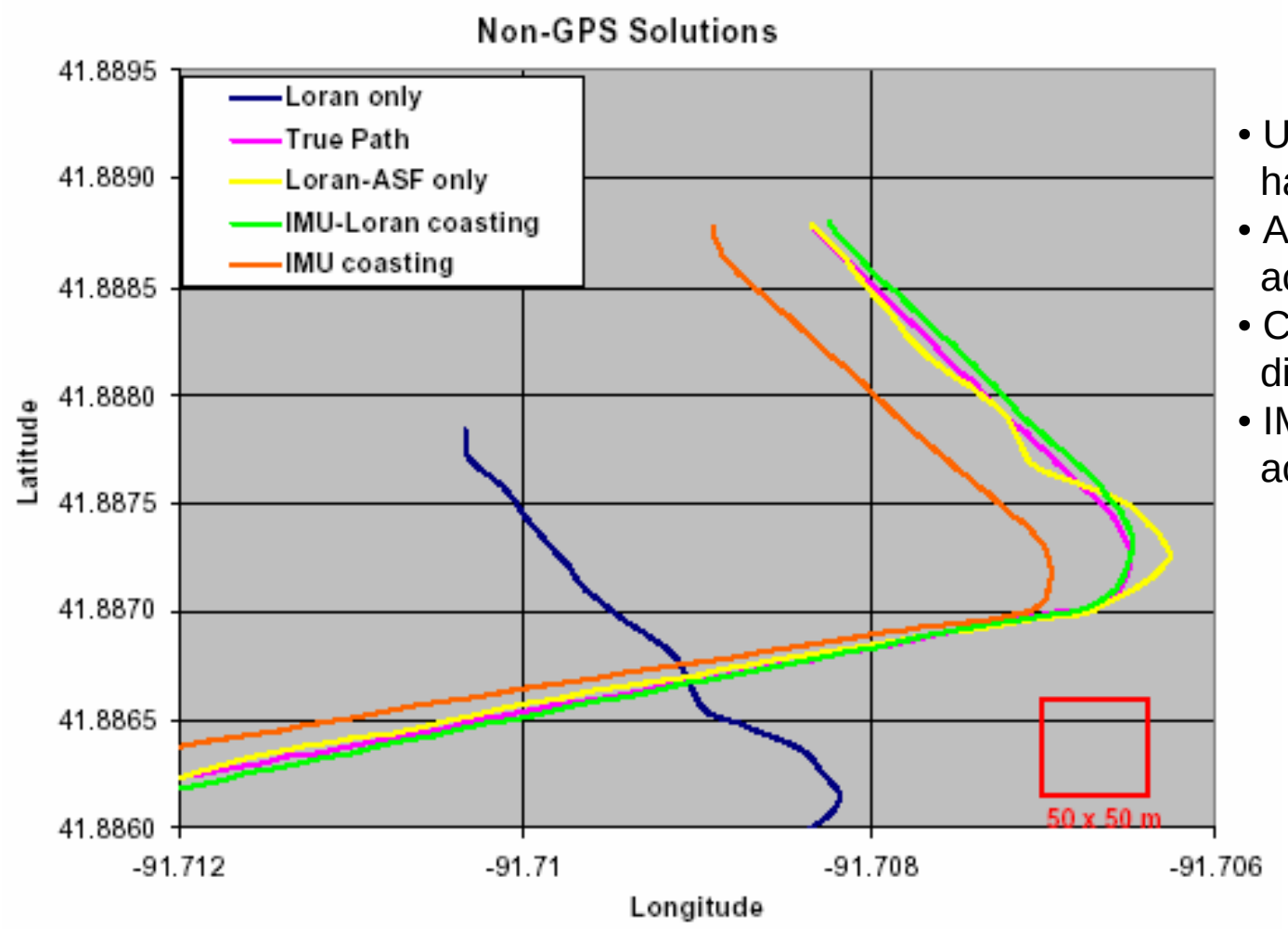
Rockwell Collins

Taxi Data Evaluation
GPS-IMU-Loran Integration



From Anderson and Doty, ION NTM, January, 2004

Taxi Data Evaluation
GPS-IMU-Loran Integration



- Uncorrected Loran has large bias
- ASF-corrected Loran is accurate but noisy
- Coasting IMU has diverging solution
- IMU-Loran has accuracy and low noise

From Anderson and Doty, ION NTM, January, 2004

FreeFlight Systems - Locus GPS/WAAS/Loran Integration Program

- Develop prototype in enlarged FFS 2101 Approach Plus
  - Locus:
    - Design custom interface/power supply board
    - Develop EMI interference mitigation technology to enable receiver operation within 2101
    - 3 operational modes for ASFs
  - FreeFlight:
    - Develop software to integrate GPS and Loran position and integrity data, including the simulated loss of WAAS, GPS RAIM, and GPS
    - Develop prototype enclosure and all associated mechanicals/interfaces, etc.

- Develop single unit GPS/Loran antenna
  - Locus:
    - Develop new H-field preamp
    - Incorporate single axis gyroscope (SAG)
    - Combine GPS and Loran antennas

GPS/Loran Integration Program

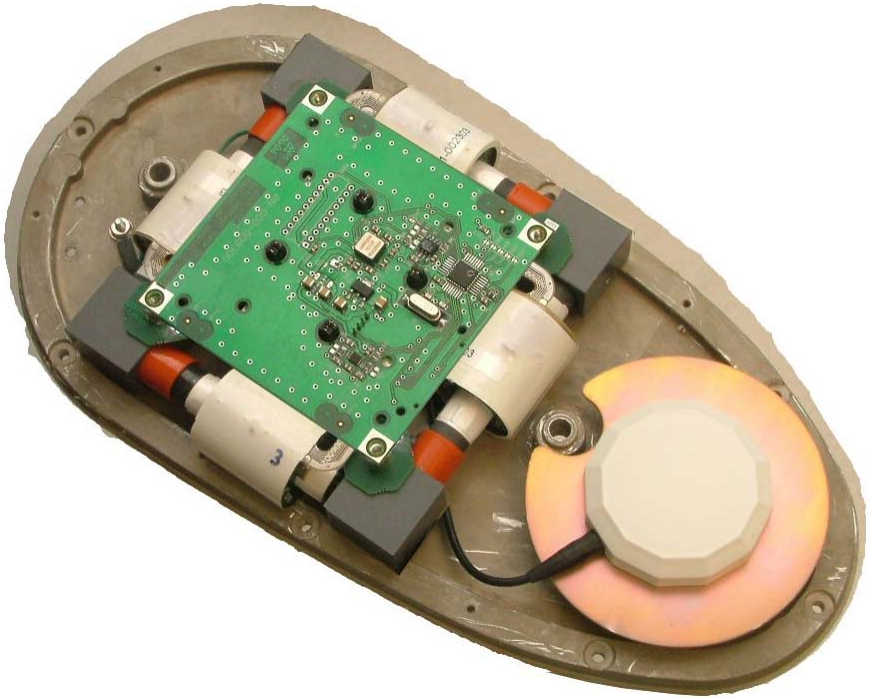
- Integration complete, hardware delivered November 30, 2004

ASF flashcard mount

Dimensions:
4.88” H (124 mm)
5.74” W (146 mm)
8.14” D (207 mm)

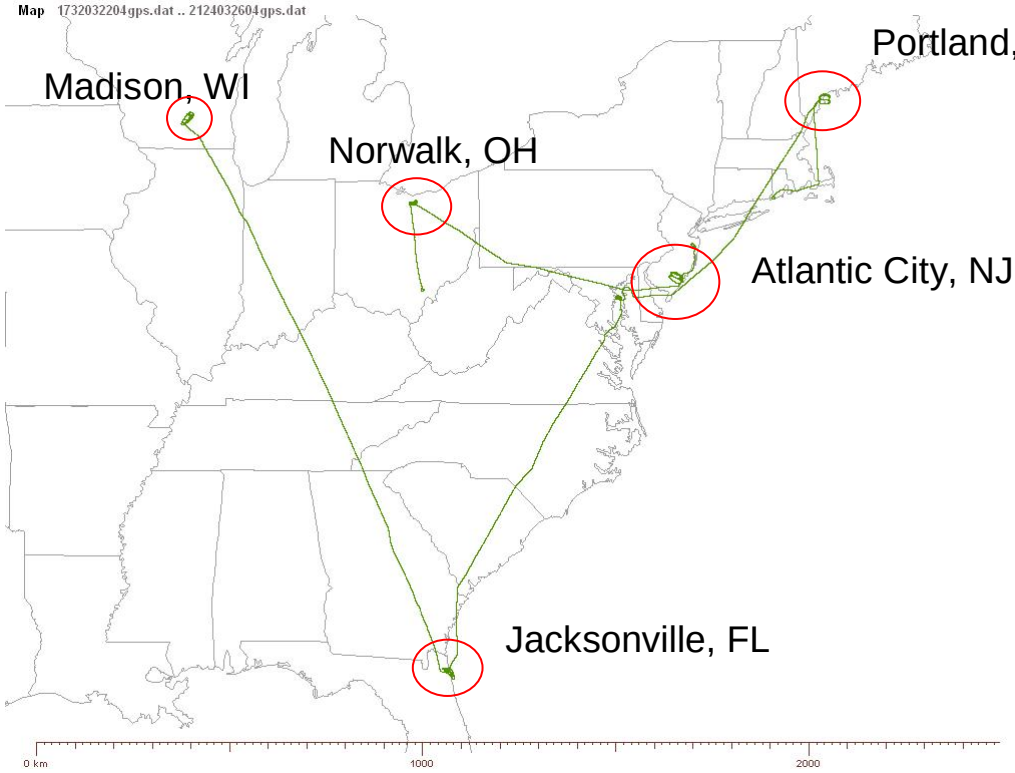
Combined GPS/WAAS/Loran Prototype with ASF Flashcard

Single Axis Gyroscope (SAG) in H-field Antenna



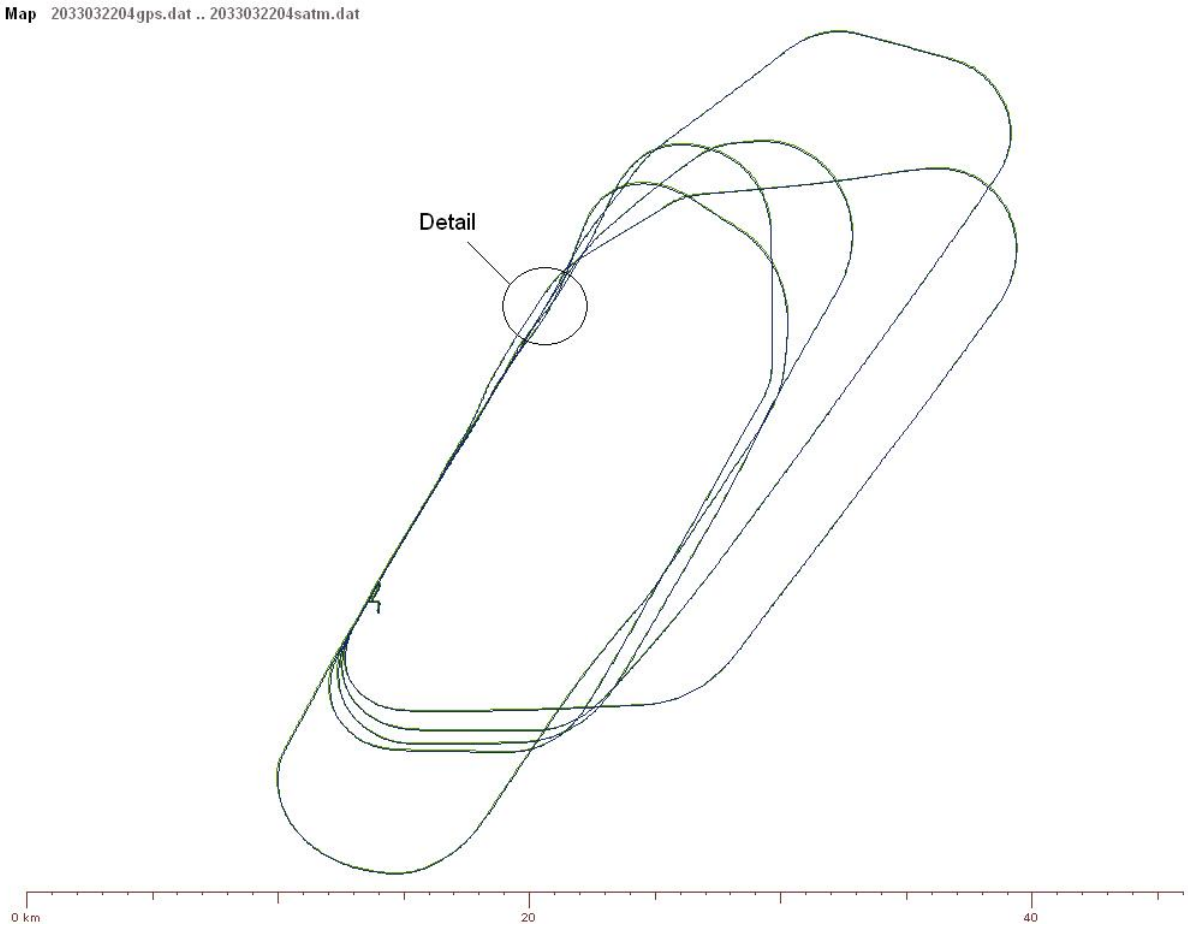
- Here SAG added to combined GPS/Loran antenna in ADF radome
- No degradation in H-field or GPS function with addition of SAG

March 2004 Flight Tests



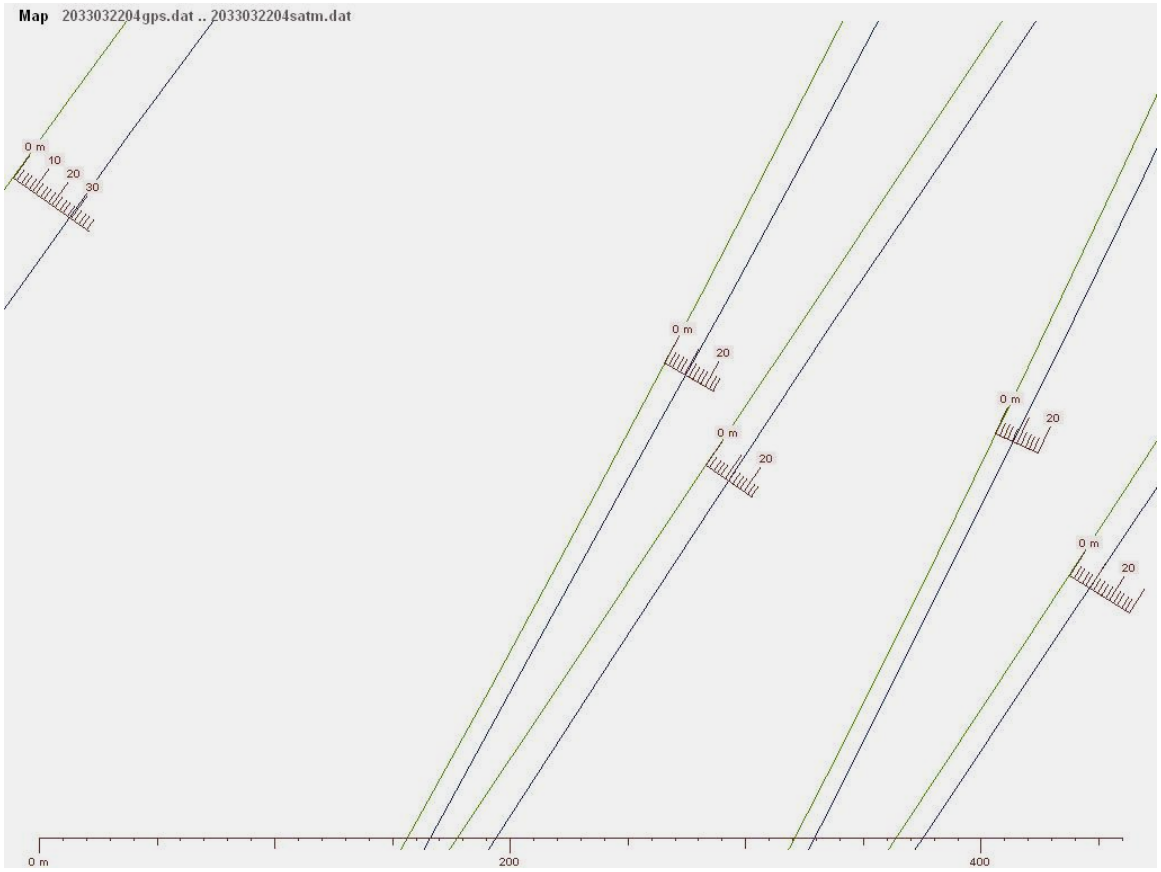
Ongoing flight tests performed by Ohio University's Avionics Engineering Center (AEC) using King Air, C-90SE twin turboprop

March 2004 Flights
ASFs from Same Day



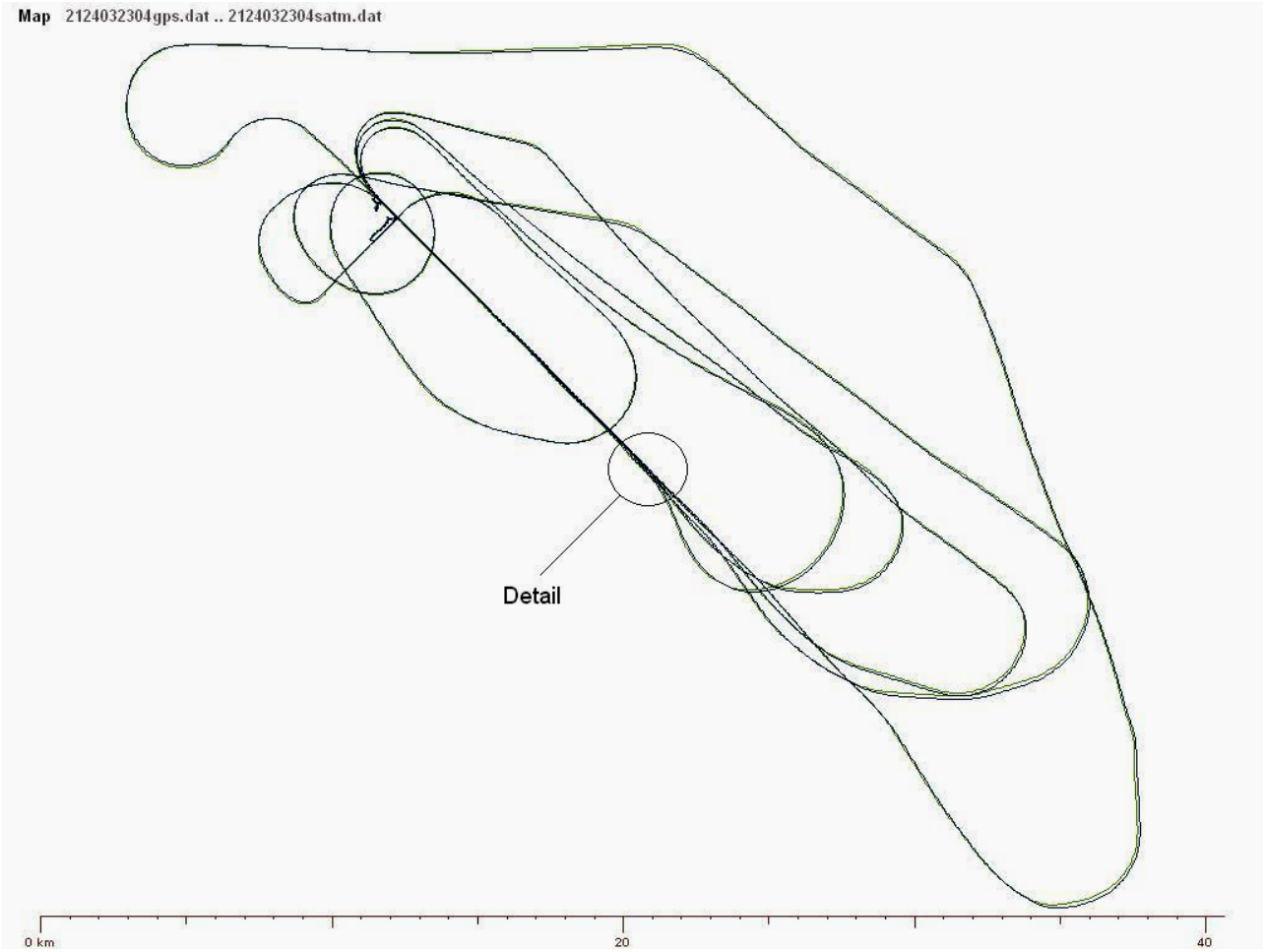
Madison, Wisconsin

March 2004 Flights
ASFs from Same Day



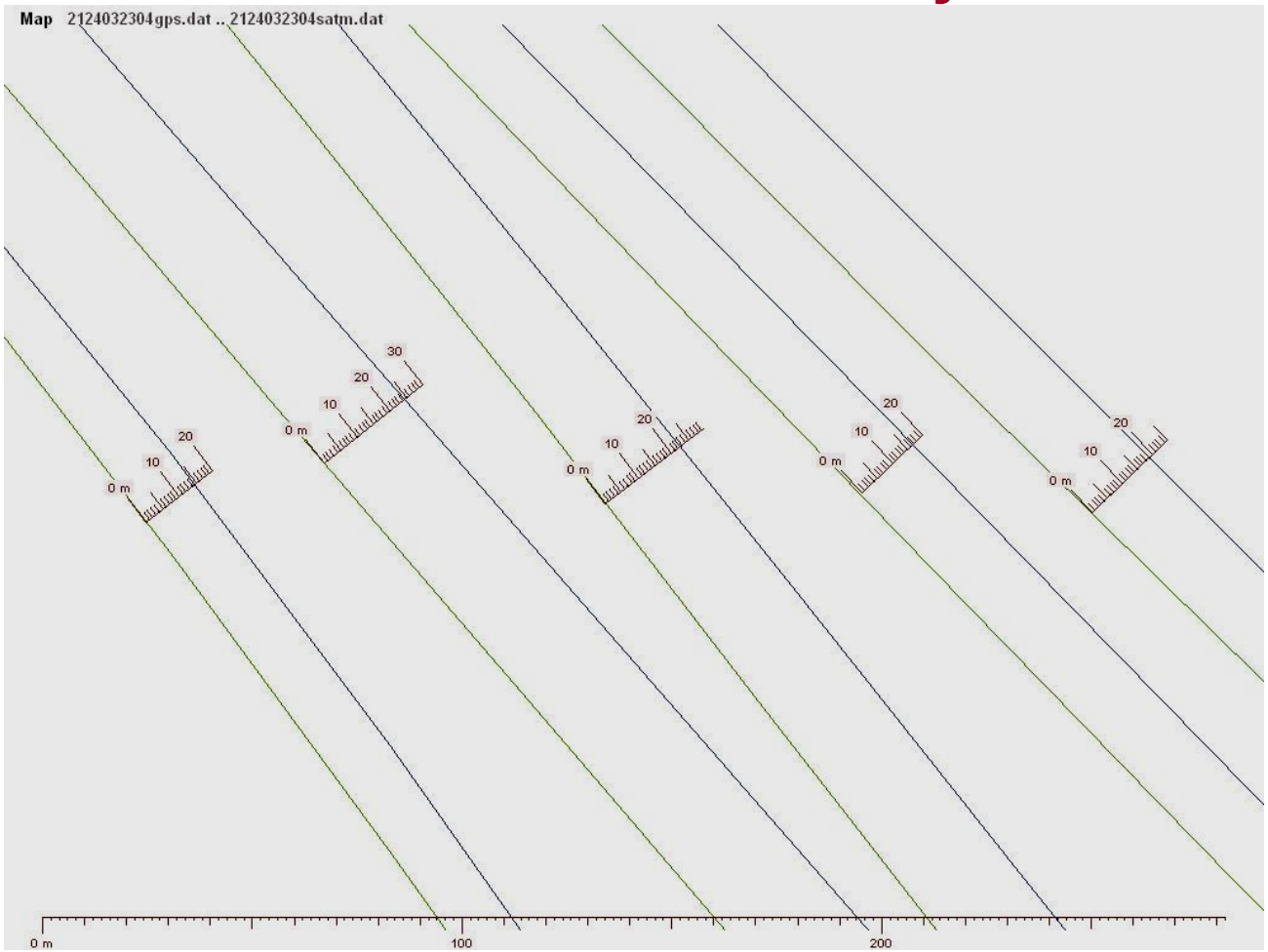
Madison, Wisconsin
Cross Track 8 - 30 m

March 2004 Flights
ASFs from Same Day



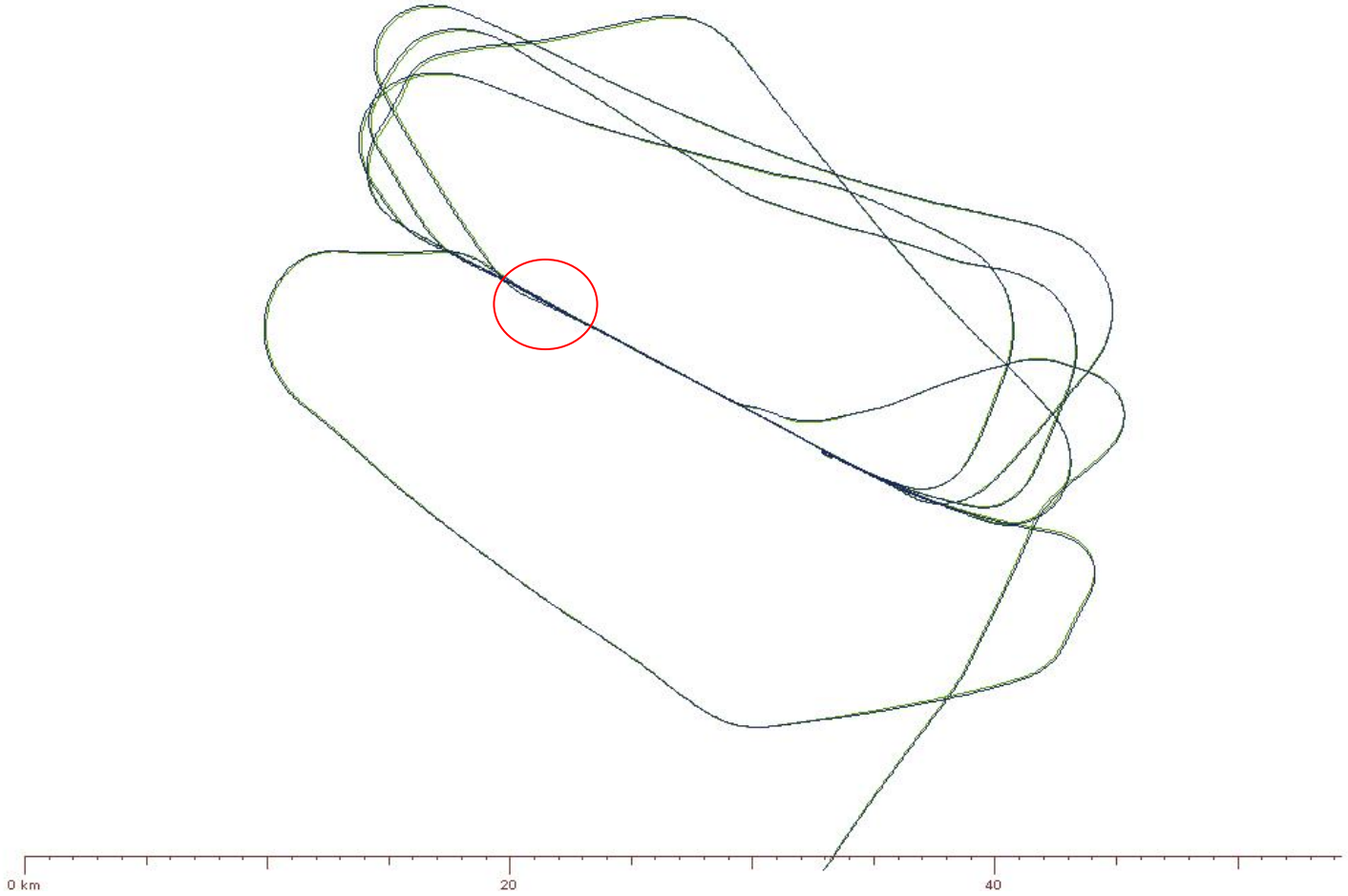
Jacksonville, Florida

March 2004 Flights
ASFs from Same Day



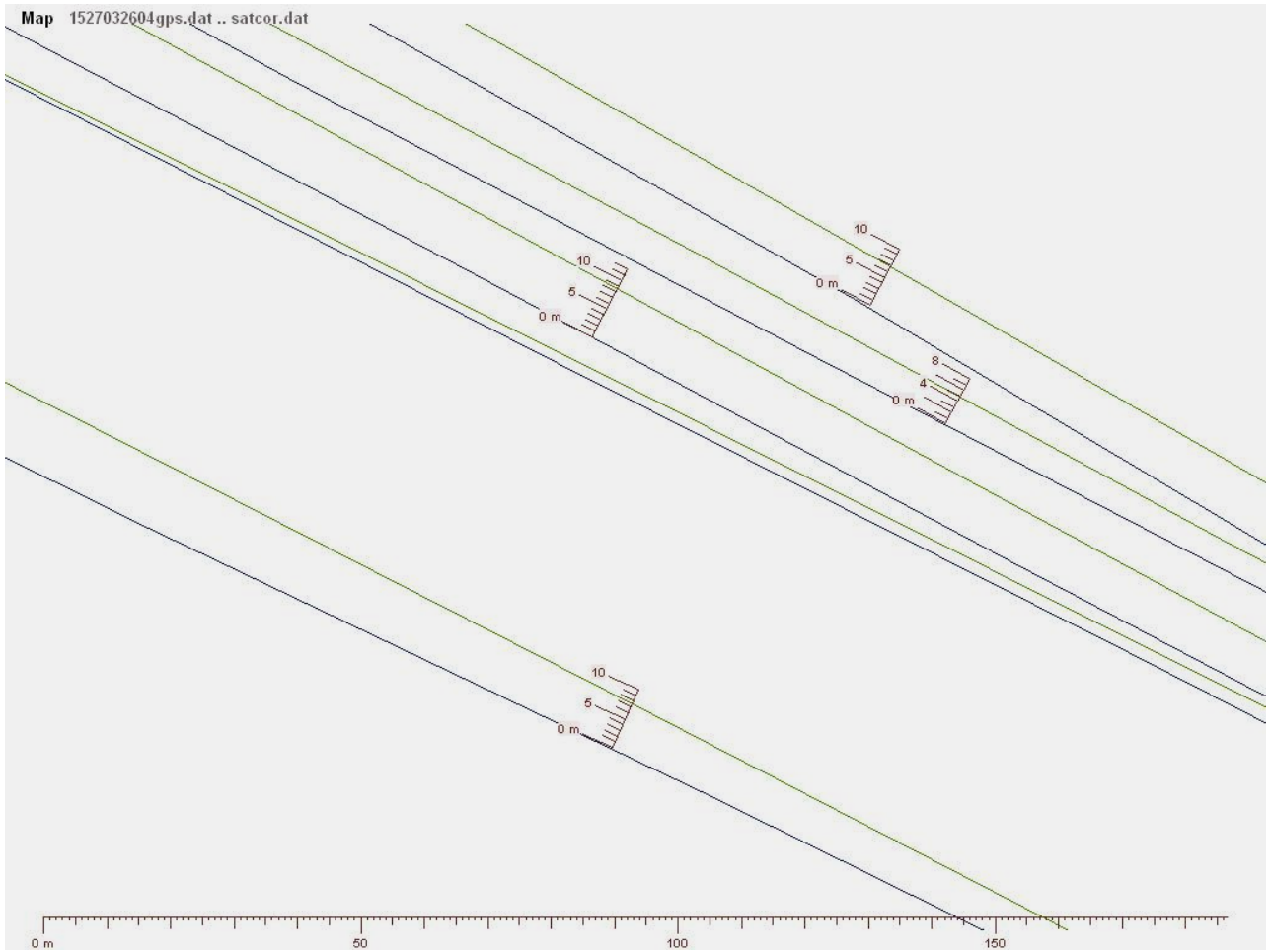
Jacksonville, Florida
Cross Track 15 -25 m

March 2004 Flights
ASFs from Same Day



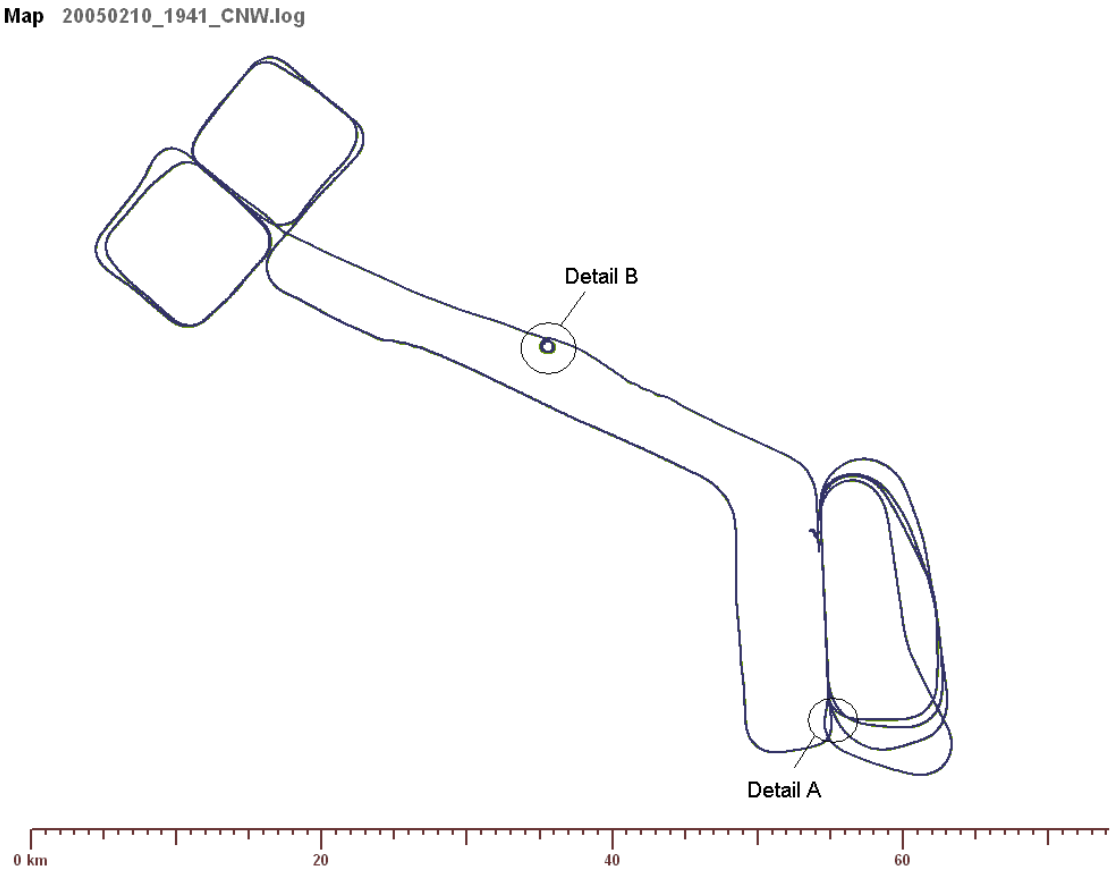
Atlantic City, New Jersey

March 2004 Flights
ASFs from Same Day



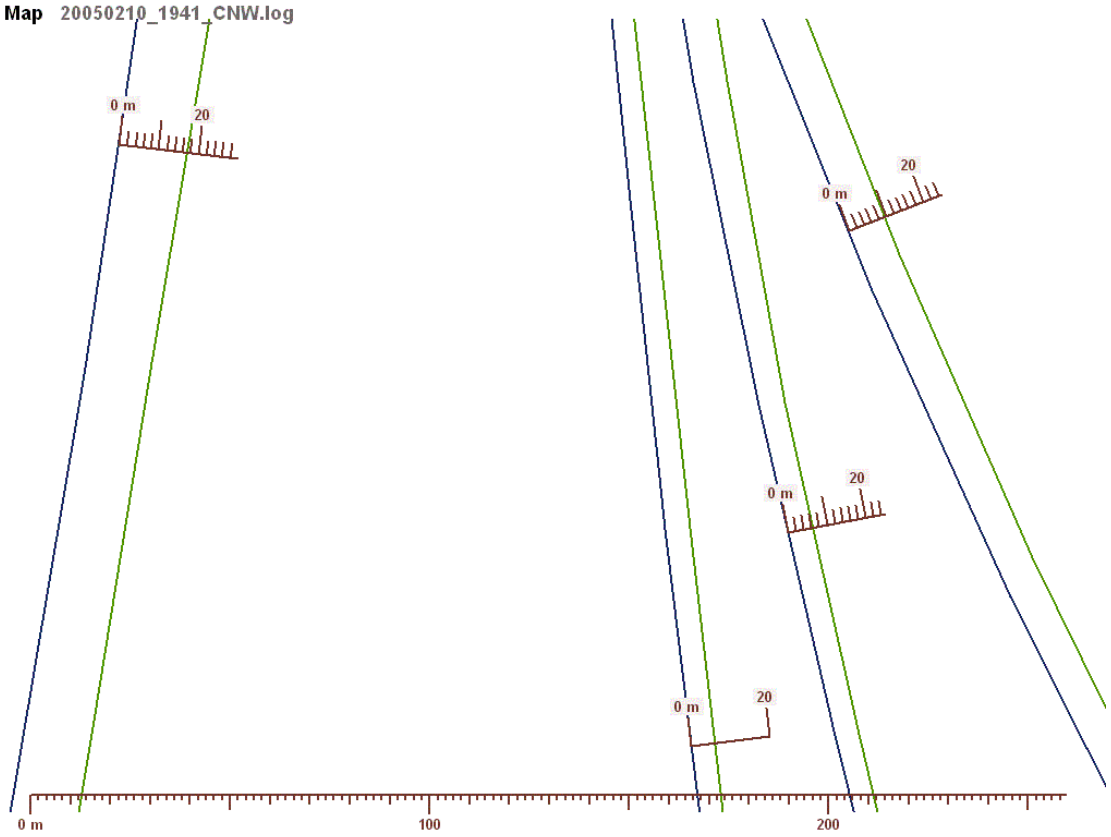
Atlantic City, New Jersey
Cross Track 1 - 9 m

February 2005 Flights
ASFs < 1 Week Old



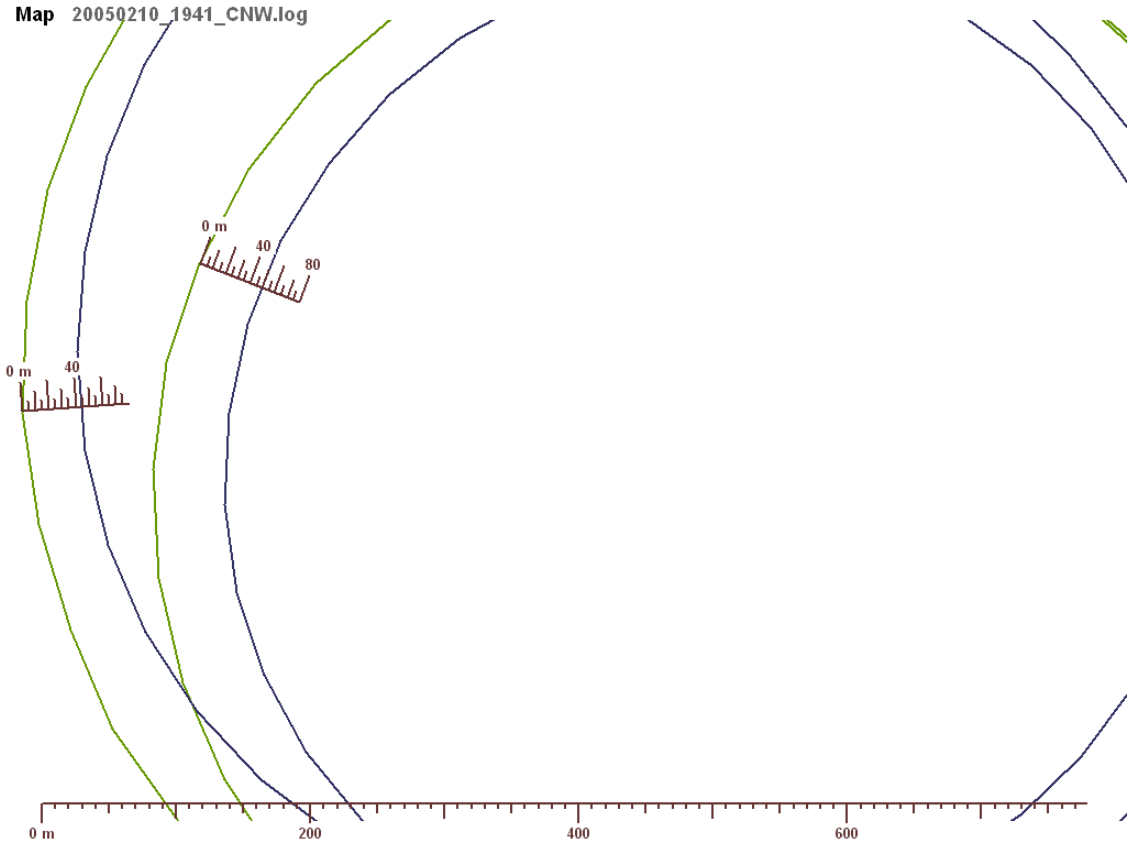
Waco, Texas

February 2005 Flights
ASFs < 1 Week Old



Waco, Texas
Cross Track 6 -20 m on Approach

February 2005 Flights
ASFs < 1 Week Old



Waco, Texas
Cross Track 45 - 50 m during 60° Bank Turn

Summary

- Resurgence in Loran interest, and new GPS policy emphasizes role of backups in critical infrastructure.
- Loran is only multimodal backup in operation, and offers highest performance as GPS backup and lowest operating expenses.
- eLoran system has passed rigorous technical evaluation and results support eLoran continuation.

Summary

- Two FAA programs have been conducted to evaluate aviation performance of integrated GPS/Loran prototype units.
- Rockwell Collins/Locus MMR prototype included various levels of GPS/Loran integration and flight tests demonstrated results well within RNP 0.3 requirements, plus enhanced integrity, availability, and continuity.
- Rockwell is continuing work on integrating an IMU sensor, and initial tests have demonstrated high accuracy, low noise results.

Summary

- FreeFlight/Locus GPS/WAAS/Loran prototype has been delivered, and includes tighter GPS/Loran integration and SAG sensor in Loran unit.

- 2005 Ohio University flight tests on FFS/Locus prototype also demonstrated results well within FAA's RNP 0.3 requirements.

- These two programs indicate Loran can meet FAA RNP and NPA requirements, and Loran appears to be an excellent candidate to backup GPS.